Quantifying Breaking-Wave Dissipation Using Nonlinear Phase-Resolved Wavefield Simulations

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Award Number: N00014-13-1-0447
http://www.mit.edu/~vfrl/

LONG-TERM GOAL

To understand and quantify wave-breaking dissipation using direct phase-resolved simulation of nonlinear wavefield evolution; and to develop effective modeling/parameterization of wave-breaking dissipation and wind forcing for phase-averaged wave prediction models.

OBJECTIVES

The specific scientific and technical objectives are:

- To characterize wave breaking events in terms of magnitude, time and location of wave energy dissipation. Obtain the spatial, temporal distribution and statistical characteristics of wave breaking dissipation.

- To quantify the dependence of wave-breaking dissipation on wave spectral parameters and investigate the effect of wave-breaking dissipation on wave spectrum evolution.

- To develop effective modeling/parameterization of wave-breaking dissipation for phase-averaged wave prediction models (such as WAM and SWAN).

- To understand energy balance in an evolving wavefield and to develop wind-forcing modeling and parameterization for phase-averaged wave prediction models.

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **30 SEP 2013**	2. REPORT TYPE	3. DATES COVERED **00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE **Quantifying Breaking-Wave Dissipation Using Nonlinear Phase-Resolved Wavefield Simulations**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Massachusetts Institute of Technology,Department of Mechanical Engineering,Cambridge,MA,02139**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**3**	

APPROACH

Direct phase-resolved simulations of nonlinear wave-field evolution are employed to investigate the characteristics and develop effective modeling of breaking-wave dissipation. The computational tool to be used is the so-called SNOW (**s**imulation of **n**onlinear **o**cean **w**aves) which has been developed and continuously improved over the past twenty years at MIT under the support of ONR. In SNOW, key physical mechanisms such as nonlinear broad-band wave-wave interactions and wave-breaking dissipation are modeled and calibrated in a direct physics-based context. Unlike statistics-based (i.e. phase-averaged) approaches, SNOW obtains deterministic predictions wherein precise ocean surface and particle velocities are given. SNOW is developed based on a high-order pseudo-spectral method, which follows the evolution of a large number (N) of wave modes and accounts for their nonlinear interactions up to an arbitrary order (M). Significantly, SNOW obtains an exponential convergence and requires a linear computational effort with N, M. It is a powerful tool for direct simulations of realistic ocean wave-field evolution.

In SNOW computations, we apply an adaptive algorithm to model the effect of wave breaking using effective filtering in the spectral domain for relatively small-scale breaking and local smoothing in the physical domain for large-scale breaking. Significantly, this approach does not involve free/adjustable parameters. This wave breaking model is found to be robust and capable of reliably predicting the energy dissipation in wave breaking events. This is validated by direct comparisons to experimental measurements of different two- and three-dimensional breaking waves before and after breaking. In large-scale nonlinear wavefield simulations, the breaking model is shown to be effective in obtaining phase-accurate wavefields involving extensive wave breaking. A powerful aspect of this SNOW capability is that the breaking occurrence in space-time does not need to be specified but is obtained from the evolution itself. By tracking the energy loss in the SNOW simulation resulting from application of the breaking model, the magnitude as well as the spatial-temporal location of the wave energy loss can be quantified. More details can be found in Yue (2008) and Xiao *et al* (2013).

To study wave breaking dissipation associated with evolving wavefields, we perform large-scale SNOW simulations of nonlinear wave-field evolution in domains of $O(10^{3\sim4})$ km^2 with evolution time up to O(1)hour. The wavefields with various spectral parameters are considered. Each simulation typically uses $N = O(10^{3\sim4})$ wave modes per dimension and nonlinearity order $M = 3\sim4$ to include modulational instability and quartet resonant wave interactions. From the simulated nonlinear wavefields, we identify various types of wave-breaking events and then characterize the associated energy dissipation. Based on these, we develop effective modeling and parameterization of wave-breaking dissipation for phase-averaged wave prediction models.

WORK COMPLETED

- ***Generation of large-scale phase-resolved nonlinear ocean wavefield evolution***. We applied the SNOW-based reconstruction/forecasting capability to generate a large phase-resolved nonlinear wavefield (3km x 3km) with long time evolution (up to 2 hours) based on the use of continuous FLIP-based radar wave measurements (from ONR HiRes program). This realistic wavefield is to be used as the necessary boundary condition in the LES computation of turbulent air-wave interactions by Peter Sullivan of NCAR for understanding the air-sea mixing processes in the ocean surface boundary layer.

- ***Characterization of wave-breaking events in phase-resolved wavefield evolution***. In the simulated phase-resolved wavefields, we identified the location and time of occurrence of wave-breaking events and quantified the associated energy dissipation. From these, the wave-breaking events are characterized in terms of location, time and magnitude of wave-breaking dissipation.

- ***Obtaining statistical characteristics of wave-breaking dissipation***. Based on the datasets of wave breaking events we collected, we obtained the spatial, temporal distribution and statistical characterization of wave-breaking dissipation. The correlation between occurrence of wave-breaking events and local wave kinematics (such as free-surface elevation, wave steepness, and particle velocity) was also studied.

RESULTS

This project has started for about a half year. The research moves forward as planned. We are in the middle of producing significant results, particularly on direct quantitative comparisons with HiRes data on the occurrence and characteristics of breaking wave events in realistic ocean environments. Additionally, we are quantifying the dependence of wave-breaking dissipation on wavefield spectral parameters.

IMPACT/APPLICATIONS

Phase-resolved computations of nonlinear wavefield evolution enable an understanding of the detailed processes of wave breaking and the associated energy dissipation, which forms the basis for developing effective modeling of wave-breaking dissipation that is of critical importance for the (phase-averaged) wave prediction tools (such WAM and SWAN).

RELATED PROJECTS

This project is related to the project entitled "High-Resolution Measurement-Based Phase-Resolved" (N00014-08-1-0610), in which the realistic phase-resolved wavefield measurements by radar, buoy, and ATM are available. From these data, we can reconstruct and predict the time/spatial evolution of the realistic wavefields and make direct comparisons with the measurements on wave-breaking related quantities.

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